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AFFDL-TM-73-5-FXG

AIR FORCE FLIGHT DYNAMICS LABORATORY
DIRECTOR OF LABORATORIES
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WRIGHT PATTERSON AIR FORCE BASE OHIO

BOUNDARY LAYER TRANSITION MAPPING AT SUPERSONIC SPEEDS MEASURED BY LIQUID CRYSTALS

E.D. McElderry

High Speed Aero Performance Branch
Flight Mechanics Division
Air Force Flight Dynamics Laboratory

January 1973

Project Number 1366
Task Number 136601
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FOREWORD

This report was prepared by E.D. McElderry, of the High Speed Aero Performance Branch, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. The work was performed as part of the AFFDL in-house research under Work Unit No. 13660108 "Boundary Layer Transition Effects on Advanced Weapons Systems", Project No. 1366, "Aeromechanics Technology for Military Aerospace Vehicles", and covers work conducted between March 1971 and December 1972.

The experimental tests were conducted by Mr. John Fehl of FXG in cooperation with personnel from the Aeromechanics Branch (FXM) of the Air Force Flight Dynamics Laboratory, and the author wishes to acknowledge their cooperative assistance.

This report has been reviewed and is approved.

Philip P. Antonatos
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ABSTRACT

An experimental program was conducted to evaluate the use of encapsulated liquid crystals as a means of mapping boundary layer transition patterns on delta wings. Since the method relies solely on surface temperature changes, one must be sure that boundary layer transition is in fact the cause for the change. Where temperature gradients caused by inviscid effects occur, there can be difficulty in isolating the true transition pattern from other effects. By varying unit Reynolds number, the temperature/color pattern associated with transition marches forward (or aft) while inviscid related patterns remain fixed. In most cases this mechanism is sufficient to separate the effects.

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ILLUSTRATIONS

LIST OF SYMBOLS

SYMBOL	DESCRIPTION
M_∞	Free-stream Mach Number
P_o	Tunnel stilling chamber total pressure
R_e/ft	Free-stream Reynolds Number per foot
Re_{tr}	Transition Reynolds Number, $(R_e/ft)\ X_{tr}$
Taw	Adiabatic wall temperature
T_o	Tunnel stilling chamber total temperature
X	Axial distance from nose along centerline
X_{tr}	Length of laminar and transitional boundary layer measured parallel to centerline
α	Angle of attack in degrees
Λ	Sweep angle of leading edge in degrees

I INTRODUCTION

The location of boundary layer transition on a three-dimensional flight vehicle can not be computed by methods presently available. Purely theoretical solutions are untractable, and empirical predictions are primarily based upon the correlation of large quantities of data over two-dimensional shapes. To compound matters, experimental data acquired in ground test facilities are known to be quantitatively inaccurate. Further, the prospects of improving theories or resolving experimental inconsistencies in the near future appear dim.

Even though the current difficulties present a formidable situation, there is one other aspect of the problem which can be investigated in ground test facilities with reasonable hope of success. That is qualitative information. The experimentalist must be able to find such things as the transition front (or local position on the body) as a function of angle of attack, geometry variations, flow conditions, etc. It is assumed that any data trends which might be established through experiment are independent of quantitative parameters.

The purpose of this test was to evaluate liquid crystals as a particular kind of thermal mapping technique for qualitative boundary layer transition data on delta wings. The method has already been found effective for flat plates (Reference 1). This is an extension of that effort by virtue of the added complexity of 3 - dimensionality of the flow.

II PROPERTIES OF LIQUID CRYSTALS

"Liquid Crystals" are compounds which are capable of existing in a mesomorphic state and exhibit some of the properties of both liquids and crystalline solids. They are, for example liquid in mobility and crystalline in optical properties.

The most optically active substances known are cholesterol esters. In general, cholesteric substances scatter light selectively when they are cooled (or heated) through their liquid crystal phase. That is, when illuminated with unpolarized white light, incident at a given angle, they reflect only one light wavelength at each viewing angle. At temperatures above or below the liquid crystal phase, the material appears colorless.

By mixing cholesteric substances in various proportions, any desired temperature-color combination may be obtained. They are usually mixed so they react to temperature changes in a continuous manner from colorless to red, to yellow, to green, to blue, to violet, and again to colorless as they are heated. The sequence is reversible for the cooling process.

It has been reported that different mixtures can be prepared so that a color change over the entire visible spectrum, from red to violet can cover a desired temperature span as small as 1.8°F or as large as 90°F. The temperature at which known liquid crystals operate range from -4°F to 480°F.

III EXPERIMENTAL PROGRAM

A. BACKGROUND

Encapsulated liquid crystals were used in a previous test program, (Reference 1) to locate transition on a sharp flat plate. Since it was the first use of these materials at AFFDL, the 2-D configuration was selected to simplify data interpretation and to compare with transition data acquired by other methods. The visual indication of surface temperature variation was remarkably good, making it easy to locate transition on the plate. The current test, using three dimensional models, is a logical extension of the earlier effort.

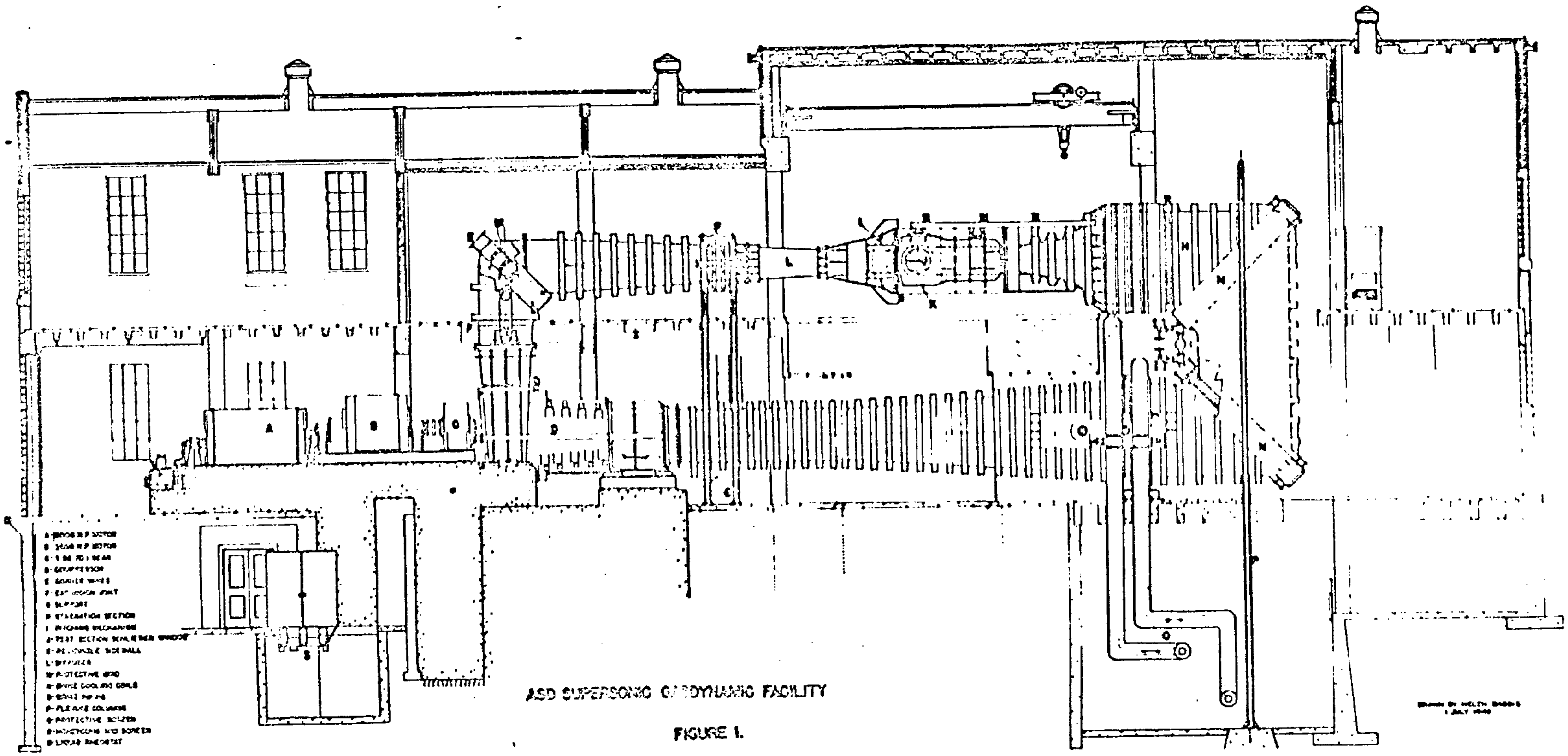
B. APPARATUS

Wind Tunnel

In-house testing was conducted in the AFFDL Two-Foot Supersonic Gasdynamics Facility (SGF). This facility is a closed circuit, variable density, continuous flow wind tunnel using air as the working fluid. A variation in Mach number is provided through the utilization of fixed two-dimensional planar nozzle blocks.

Stagnation section pressure and temperature can be set by the operator and are automatically controlled to within ±1 psf and ±1°F respectively.

Figure 1 is a sketch of the general layout of the Tunnel.



ASD SUPERSONIC GASDYNAMIC FACILITY

FIGURE I.

Models

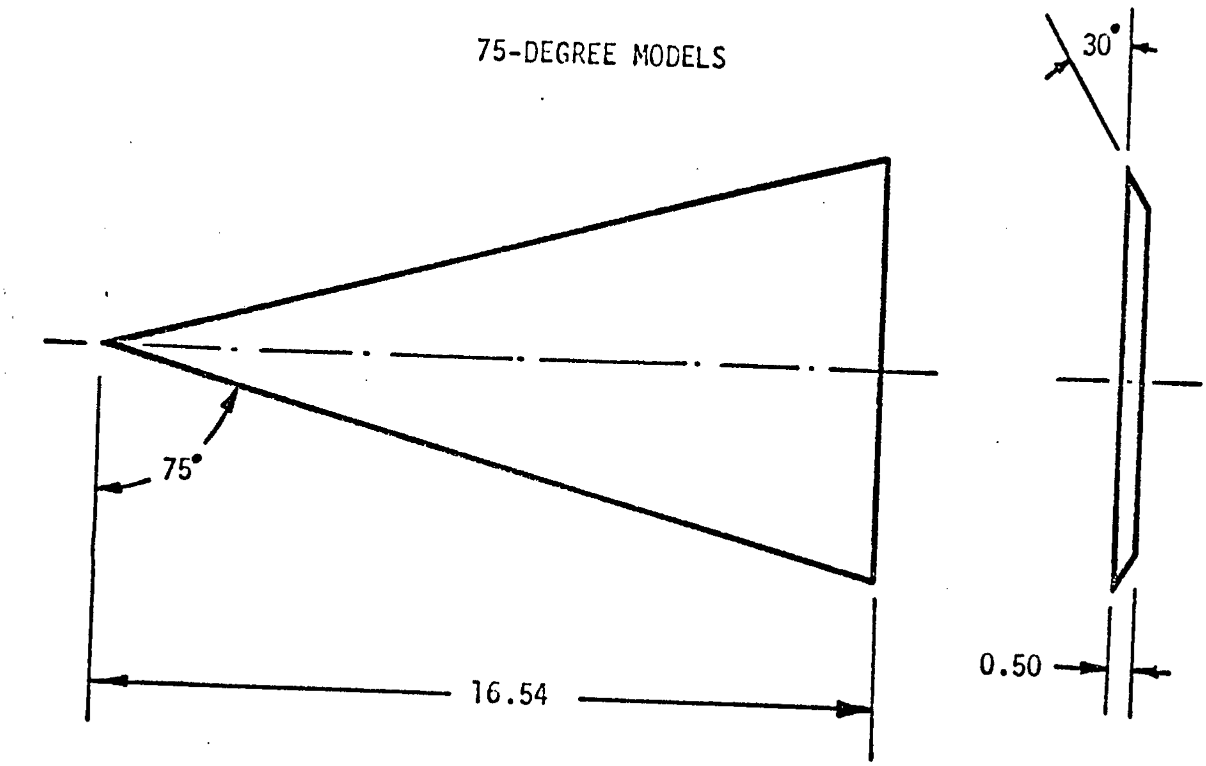
Four delta-wings were used in the test program - a sharp and a blunt 75-degree sweep pair of models and a similar pair of 80-degree sweep models. Figures 2 and 3 show overall dimensions for each. These models were made of plexiglass for low thermal conduction.

Edges were fabricated separately for each model and bonded to the basic flat swept slabs so that they were about .012 inches higher than the surface (see section A-A, Figure 3). The sheets of liquid crystals were bonded to the flat surface with two-sided masking tape to level the entire surface. A small discontinuity around the edges of the liquid crystals was almost impossible to eliminate completely, which is a disadvantage of the coated sheet type materials.

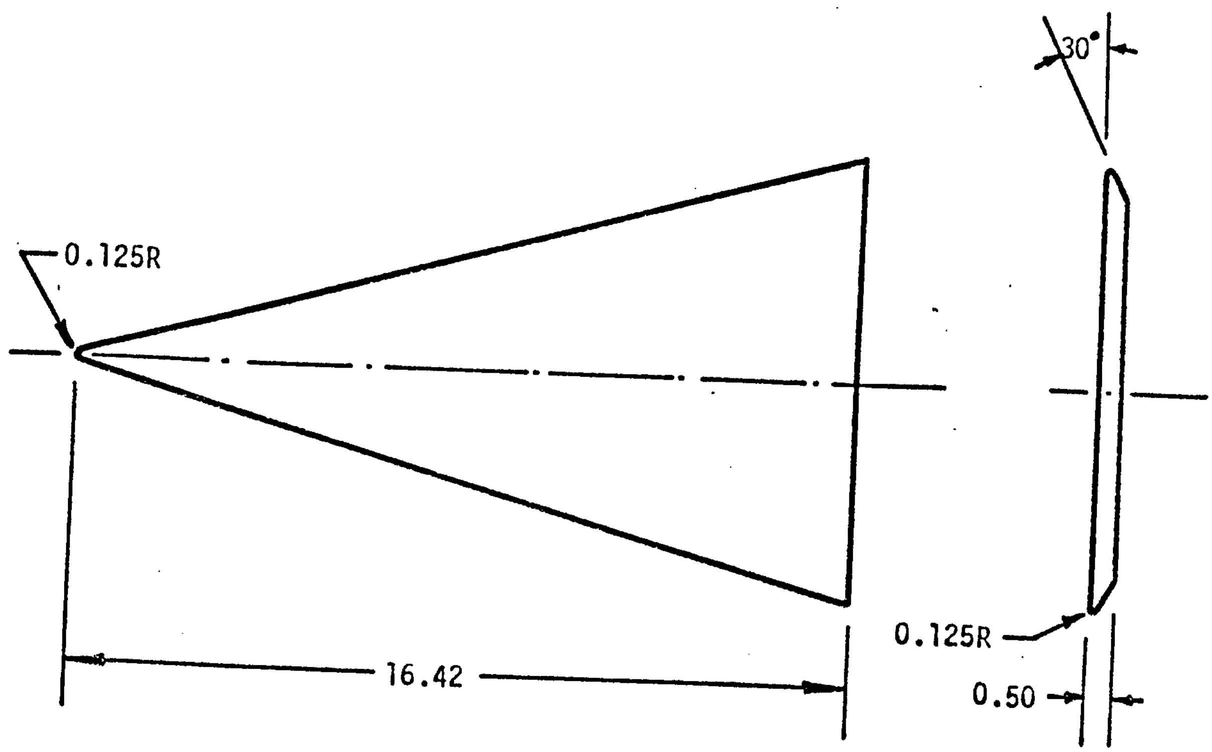
C. TEST DESCRIPTION

The entire test program was conducted at a free stream Mach number of 3. Unit Reynolds number was varied from $.5 \times 10^6$ to over 3×10^6 by incrementing P_o from 500 psf to 3000 psf in steps of 500. Total temperature was controlled to give the best color pattern on the model and generally fell in the range 112°F to 120°F. This produced a wall temperature in the range of optical activity of the liquid crystals, which was 66.2°F to 77°F and considered adiabatic. Figure 4 shows the correspondence between color (wavelength) and temperature for the NCR W-19 type formulation.

75-DEGREE MODELS



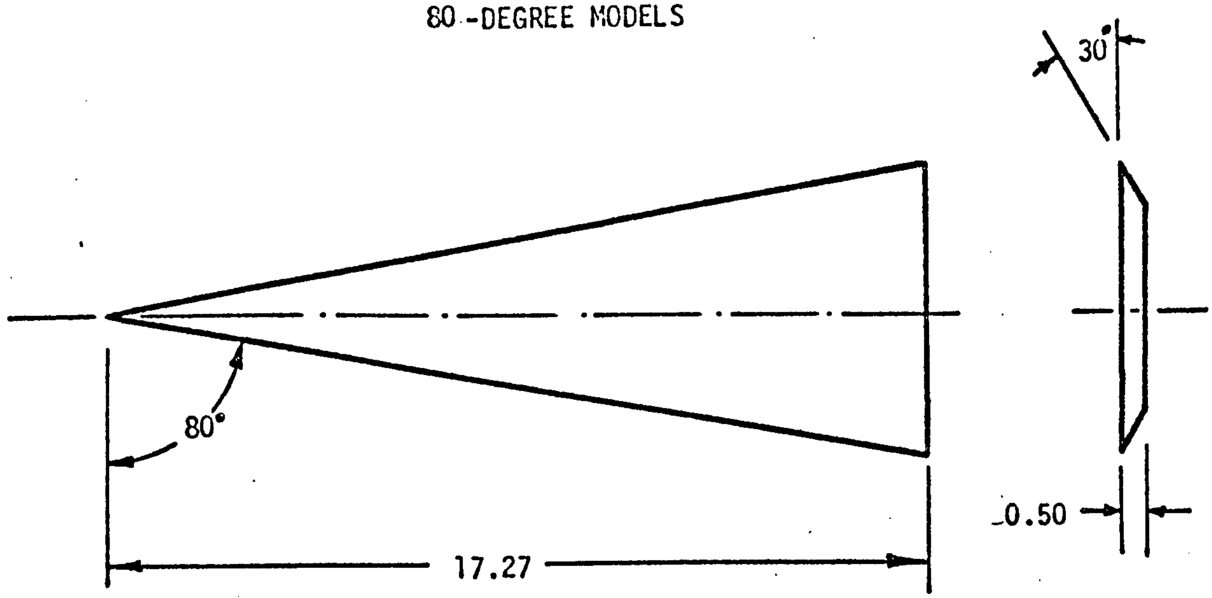
a. Sharp Edge Model



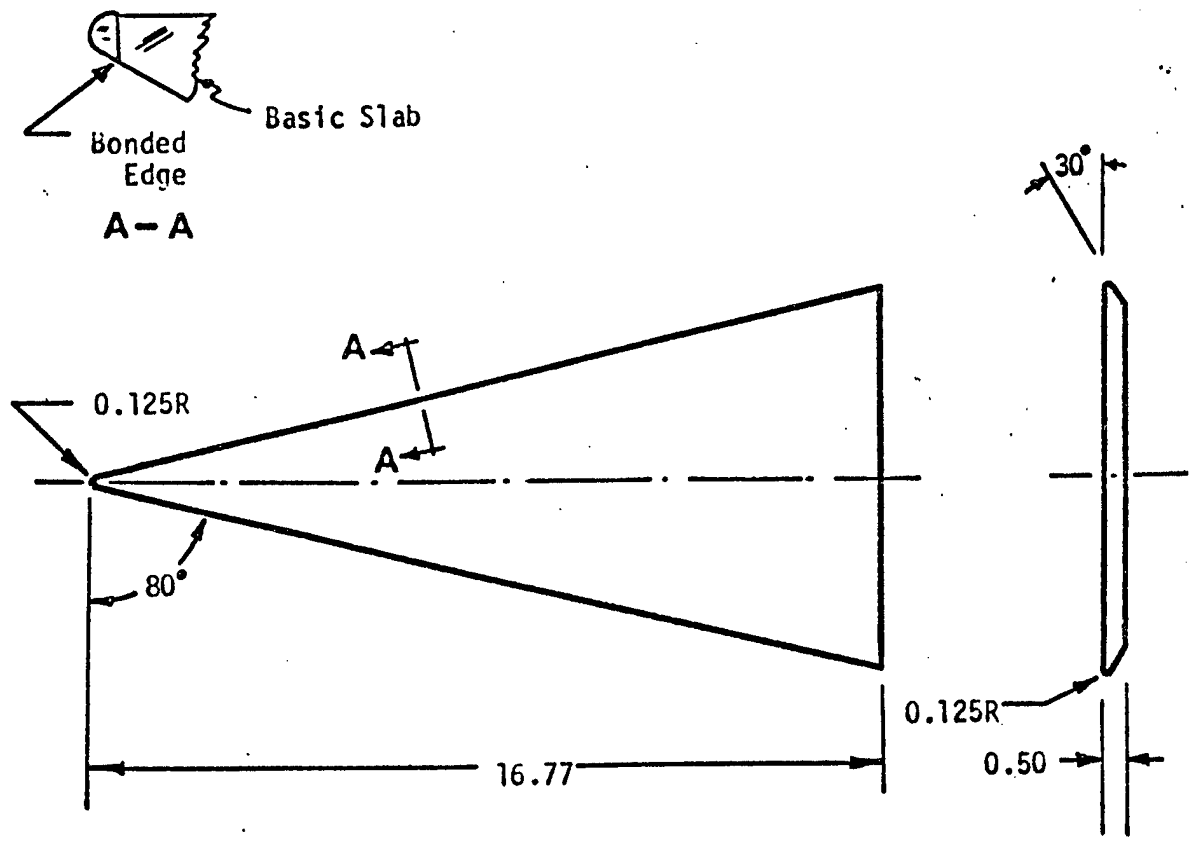
b. Blunt Edge Model

FIGURE 2 - MODEL SKETCHES, 75° DELTAS

80-DEGREE MODELS



a. Sharp Edge Model



b. Blunt Edge Model

FIGURE 3 - MODEL SKETCHES, 80° DELTAS

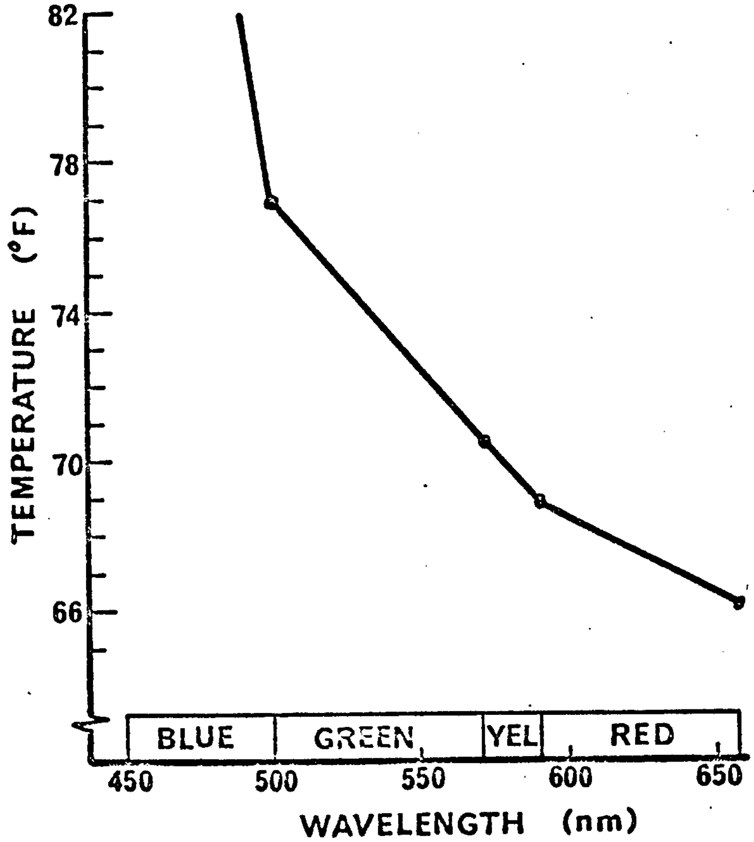


FIGURE 4 VARIATION OF TEMPERATURE WITH COLOR PRODUCED

Two angles of attack in addition to zero degrees were obtained by fitting wedges (of either 5 or 10 degrees) between the model and the model support. This device had to be used because the model is rolled 90 degrees to face the side window and the pitch plane is then the yaw plane.

IV DISCUSSION OF RESULTS

A. Centerline or Quasi-Centerline Data

It was established in Ref 1 that the most accurate means of determining boundary layer transition location using liquid crystals was to find a peak or maximum surface temperature rather than a temperature increase. On a two-dimensional sharp flat plate at zero incidence, there was no difficulty in using this procedure. A three-dimensional body, however, can have temperature gradients and peaks which are not necessarily associated with transition. As a result, it is not immediately clear from viewing a single photograph which temperature/color pattern is representative of transition and which is representative of some other flow phenomenon.

Since transition is primarily dependent on Reynolds number at constant Mach number, unit free stream Reynolds number was varied for each model geometry and attitude to provide the mechanism for sorting out transition from any other phenomenon which could effect surface temperature. In the flat plate tests of Ref 1 transition Reynolds number (Re_{tr}) varied with unit Reynolds number to the 0.4 power exactly. The delta wing tests showed the same variation as illustrated in Figure 5. All of the transition Reynolds numbers in these figures are based on lengths measured from the geometric noses of the models along the centerline to some point on or near the centerline which was most readily identifiable as a peak or maximum surface temperature. This point is discussed further in the following

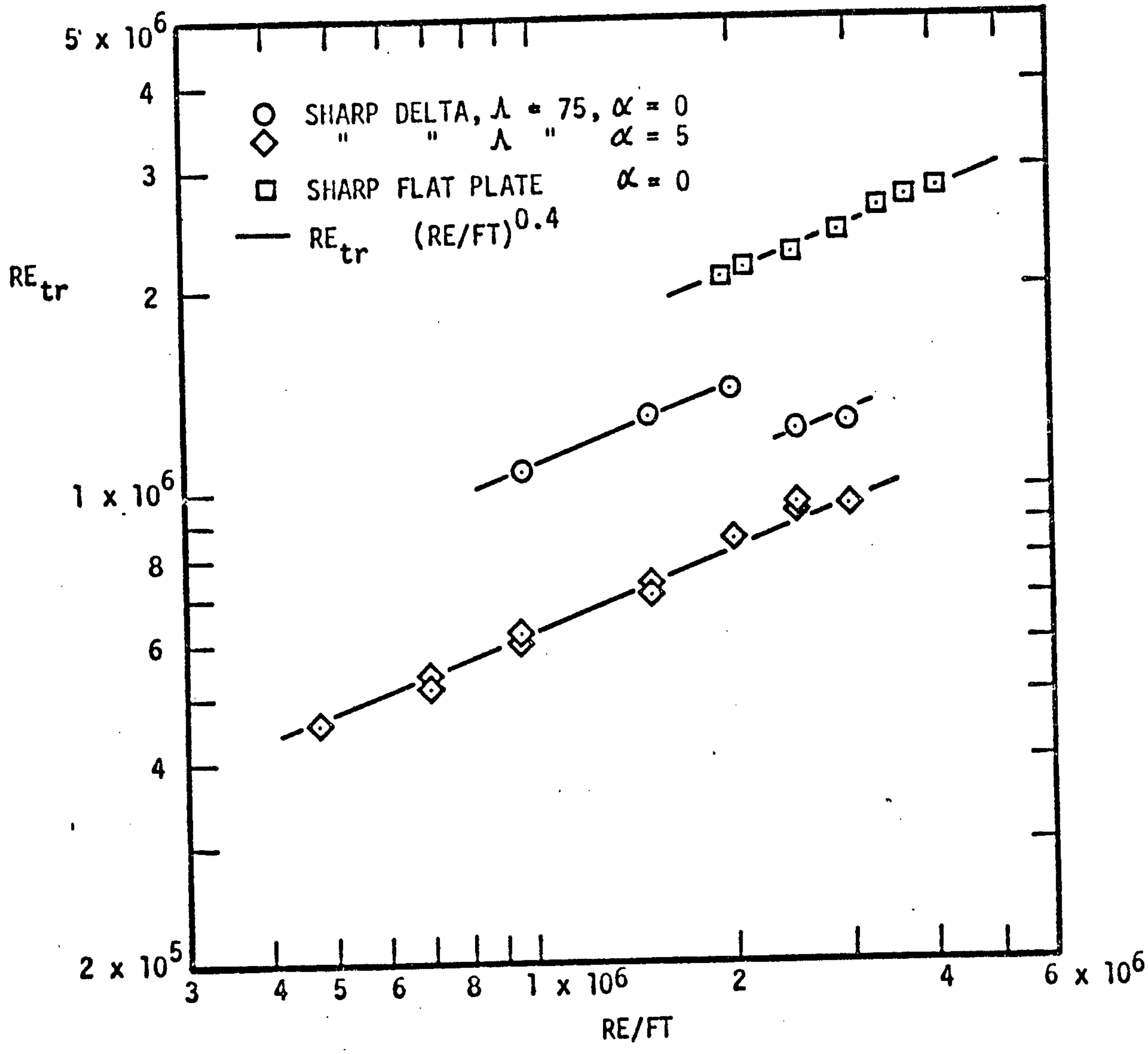
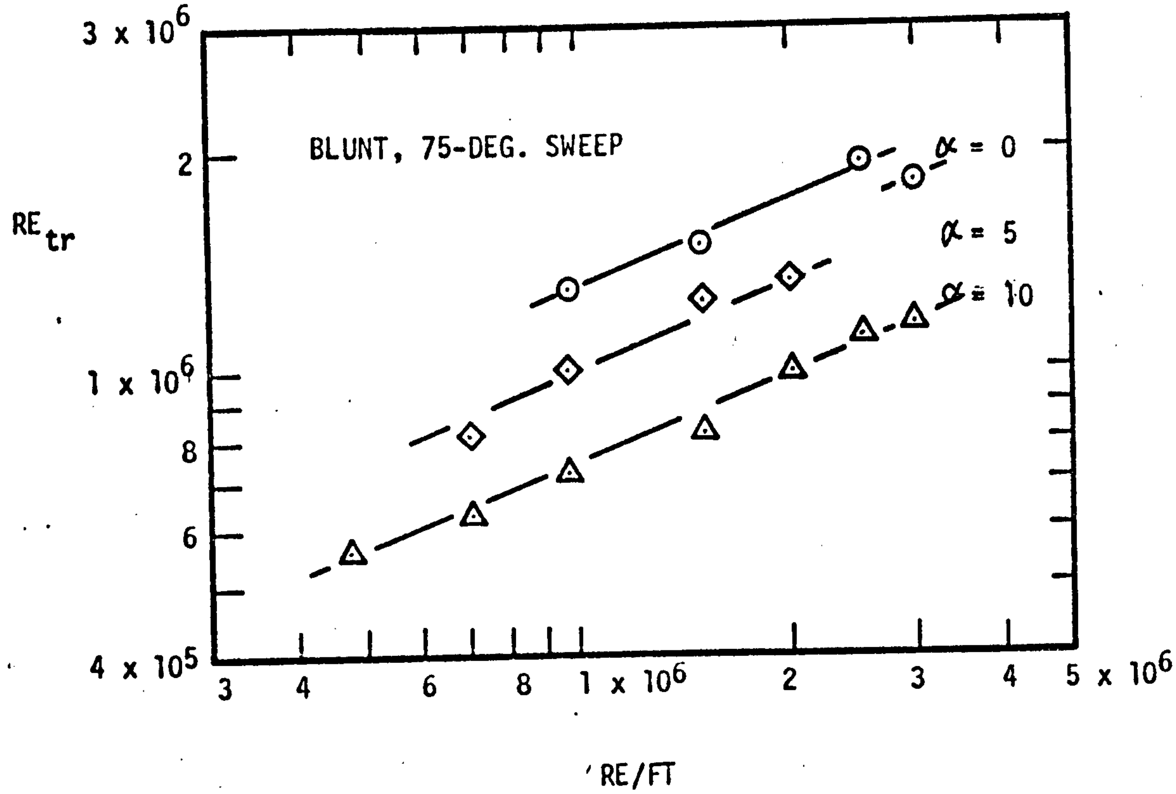


FIGURE 5 TRANSITION REYNOLDS NUMBER VARIATION WITH UNIT REYNOLDS NUMBER



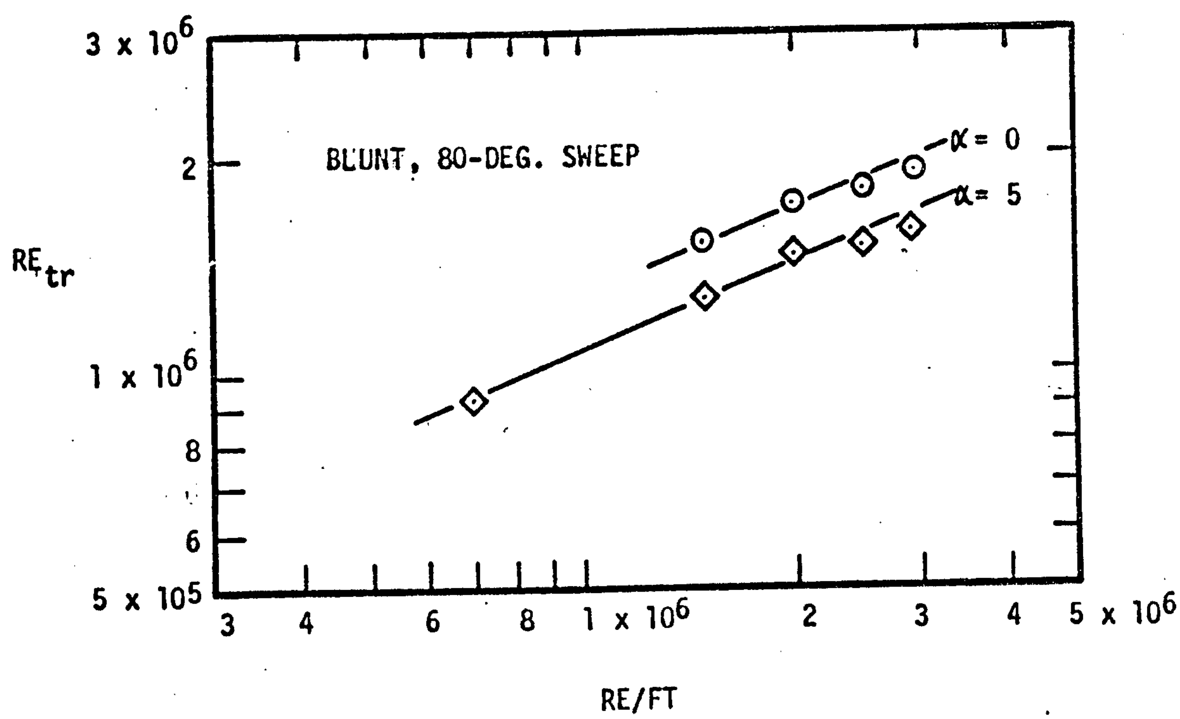


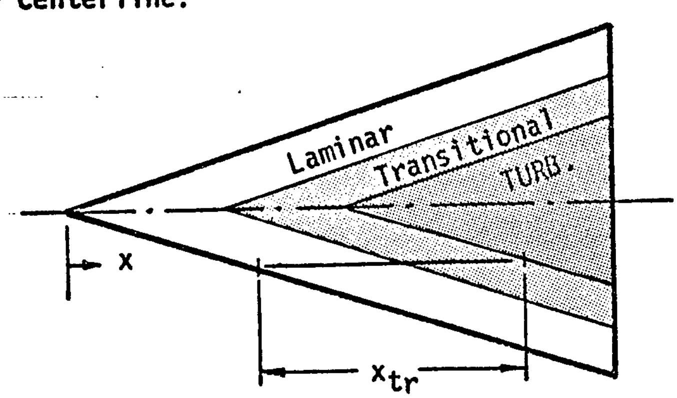
FIGURE 5 CONT'D

section. The plots are presented only to verify that transition could in fact be determined by the liquid crystals method on a delta wing. Data for the sharp 80-degree sweep model was rejected because the nose tip was broken, creating a small foreward facing surface normal to the flow.

It should be emphasized that none of these data should be compared quantitatively against each other. Any particular set of points (variation only with unit Reynolds number) had color patterns which were similar, thus enabling the selection of a unique temperature color peak for that set. From one case to the next, however, different criteria were used, depending primarily on the ease of identifying a particular color spot as it moved forward.

B. Surface Map of Transition

On a delta wing, the surface map of the transition pattern is normally assumed to be a triangular area similar to the planform of the delta as shown in the sketch below. The transition length - X_{tr} may be measured from any point on the leading edge to the transition location parallel to the centerline. Obviously X_{tr} = const for any spanwise location, and the forwardmost transition point occurs on the centerline.



From the data photographs of the present test program, the following deviations were observed relative to the assumed surface maps of transition patterns:

1) At $\alpha=0$ the apparent turbulent region was not triangular, but quasi-parallel with the centerline. See Figure 6.

2) At $\alpha>0$ and low Reynolds number the pattern was nearly triangular except near the front at the centerline, where transition appeared to be delayed for both sharp and blunt models. See Figure 7.

3) At $\alpha>0$ and high Reynolds numbers, transition approached the leading edge at the base faster than at the nose, causing a curved pattern. See Figure 8.

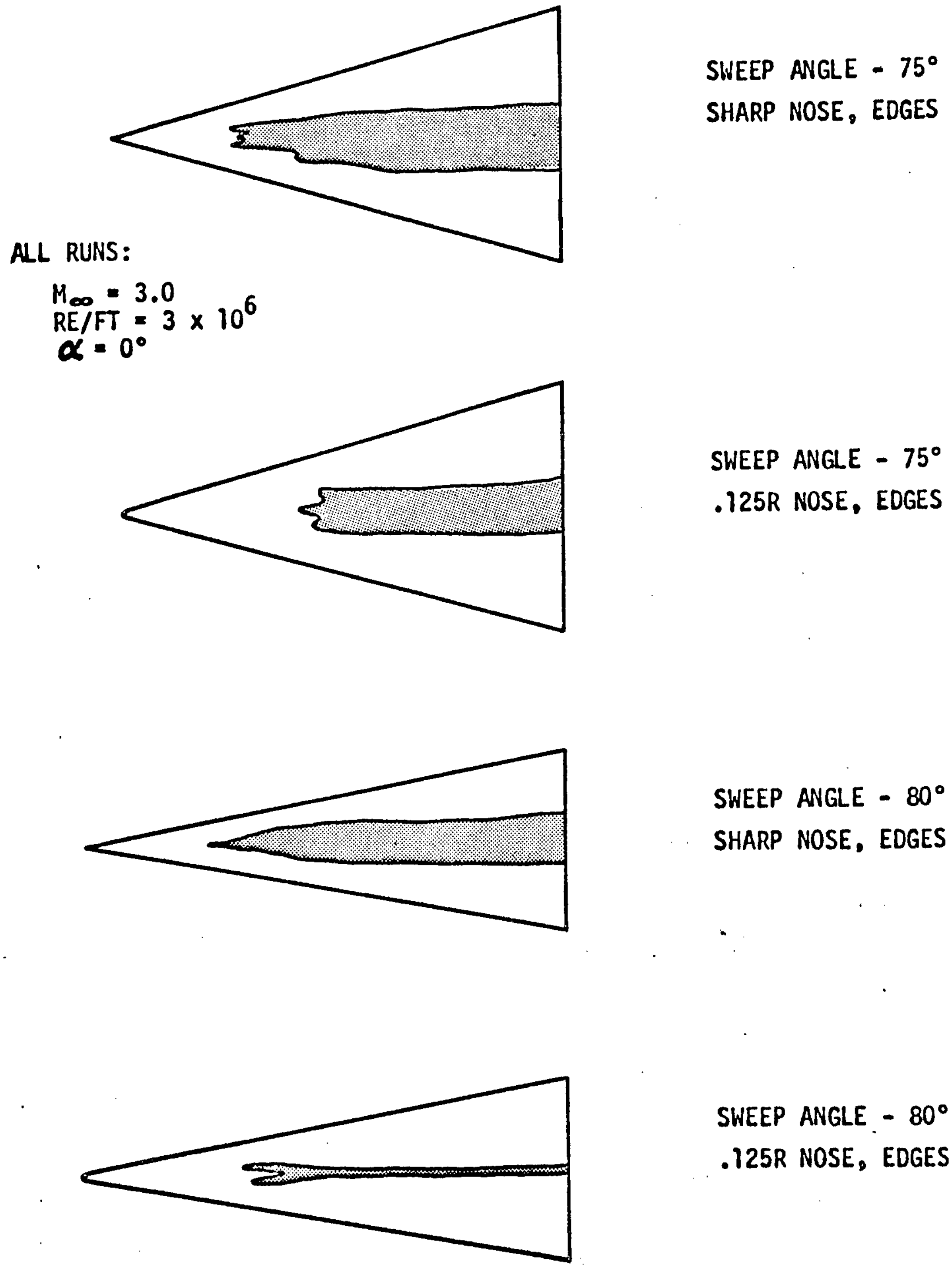
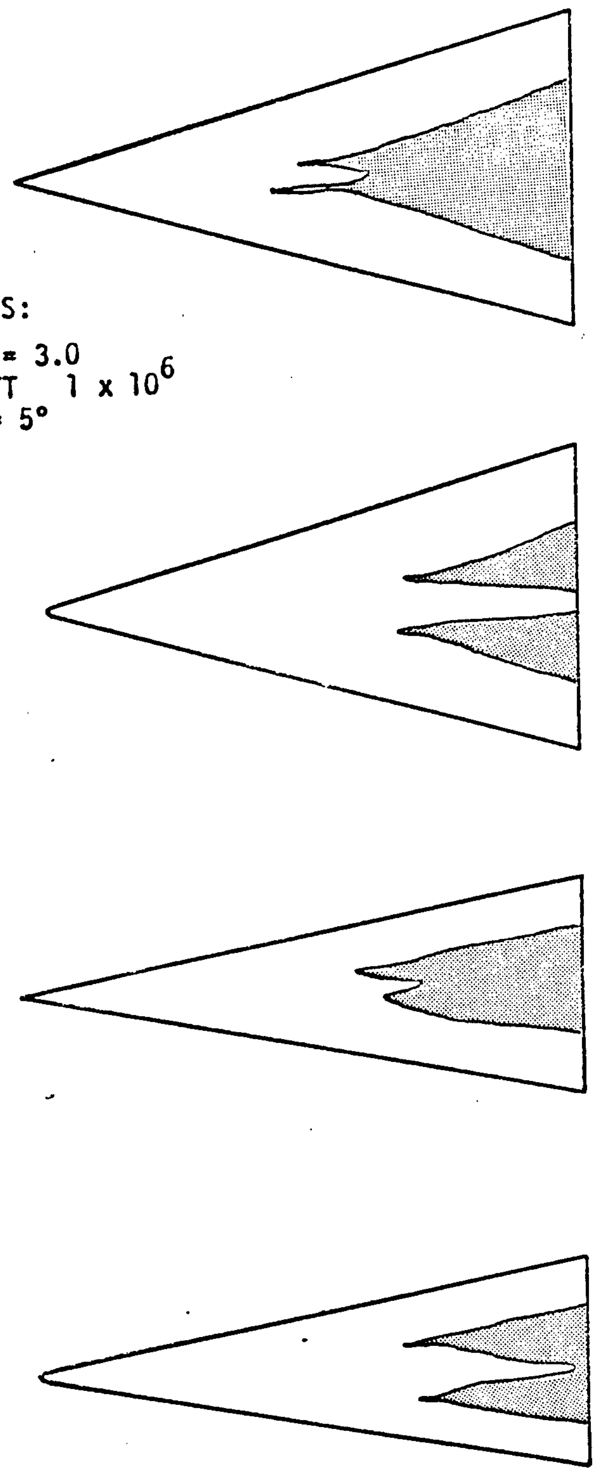


FIGURE 6 - TRANSITION PATTERNS AT $\alpha = 0°$



SWEEP ANGLE - 75°
SHARP NOSE, EDGES

ALL RUNS:
$M_\infty = 3.0$
RE/FT 1 x 10^6
$\alpha = 5°$

SWEEP ANGLE - 75°
.125R NOSE, EDGES

SWEEP ANGLE - 80°
SHARP NOSE, EDGES

SWEEP ANGLE - 80°
.125R NOSE, EDGES

FIGURE 7 - TRANSITION PATTERNS AT α = 5°

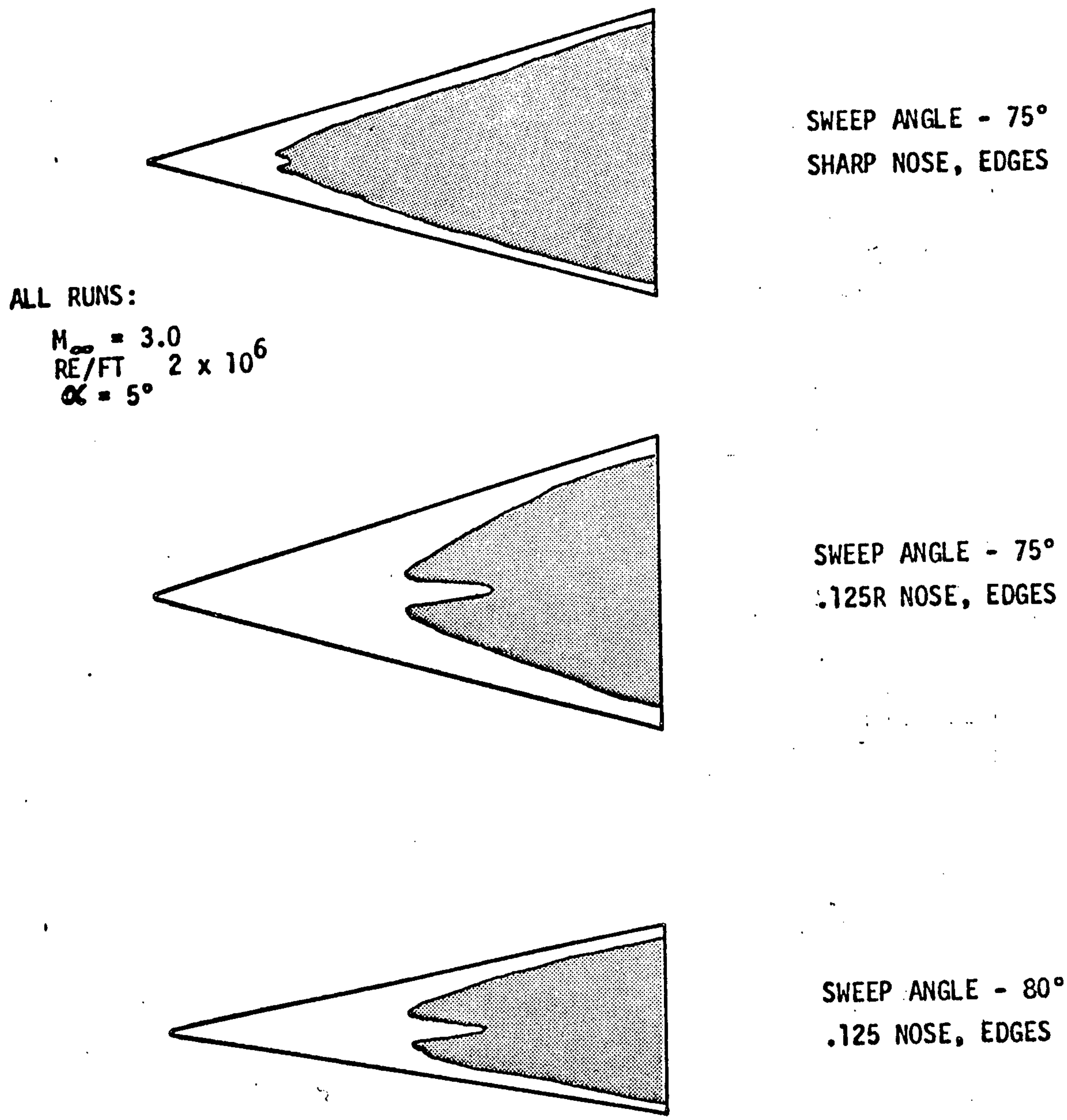


FIGURE 8 - TRANSITION PATTERNS AT $\alpha = 5°$

V REFERENCES

1. McElderry, E.D. Boundary Layer Transition at Supersonic Speeds Measured by Liquid Crystals, FDMG TM 70-3, June 1970.